MINERAL PHYSIOLOGY

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AN ADDRESS DELIVERED BEFORE

VASSAR BROTHERS' INSTITUTE,

POUGHKEEPSIE, N Y.,

November 28, 1882.

By T. STERRY HUNT, L. L. D., F. R. S.

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BY T. STERRY HUNT, LL. D., F. R. S.

In accepting an invitation to address you on this occasion, I have considered that, although the plan of your Institute includes letters and art as well as natural science, you have honored me with your choice because I have become somewhat known to you as a student of the latter, and will expect from me a discourse on some theme relating to that division of human knowledge. At the same time, a consciousness of my own deficiencies and limitations would prevent me from attempting to speak of subjects which rightly belong to other students. I shall therefore content myself with a discussion of some of the relations of science to nature, which may serve as an introduction to the consideration of certain problems of the inorganic world connected with geological history.

The term science, when used without qualification, is vague, and requires farther definition. Any organized branch of human knowledge is properly called a science. Thus, for example, there is a science of mathematics, a science of psychology, a science of theology, and a science of political economy; but in popular language we mean none of these when we speak of science. To the mathematician belongs the study of space and of number, and to others the consideration of man in his intellectual, moral, social and political relations, but by a general understanding the scientific man is one who is learned in some branch of science or knowledge pertaining to the material world; in astronomy, physics, chemistry,

mineralogy, geology, botany, zoology, or anthropology; in other words, in some department of the physical universe which we call Nature.

All such knowledge was by Aristotle included under the head of Physics, which, in its wider sense, means the science treating of the properties and the processes of physical or natural things; the study of which, in his scheme. preceded Metaphysics. It will aid us in our present survey if we learn what is the true significance of the word physics, and its derivatives physical, physiology, etc. The Greek word from which we have made physic and its plural physics comes from the substantive *physis*, which itself is derived from a verb signifying to grow, and means the act or process of growing. This is illustrated by the Greek word *phyton* from the same root, which was used to designate a plant, or in a secondary sense, a child or living creature. Hence the term phytology, meaning the science of plants. The word physics thus signifies primarily,—growing or living things.

The Greek *physis* was correctly rendered by the Latin *natura* (nature), which also means birth or development. The whole material world was thus understood by the ancient Greek philosophers as something perpetually growing, becoming or being born, and the conception underlying this view is that of incessant movement, birth and growth, followed necessarily by death and decay, which is the law of all material things. Nothing in the universe is stationary or stagnant; everything is undergoing a process of change more or less rapid. This is the meaning of the movement or flux of all things, taught by Heraclitus. Not only the organic world, but the solid crust of the earth, which is to most of us the type of stability, is subject to constant mutation. A growing plant is still to us, as to the Greek of old, the best type of a physical or natural object, for the words are synonymous. The adjective *natural* still keeps its meaning as designating that which is according to the regular process of things; and although we have come to use the word *nature* in a secondary sense for the essential qualities or characters alike of a material object and a concept, as when we speak of the nature of things, or of man's moral nature, the use of these terms

can scarcely mislead. To speak of man's physical, that is to say his natural nature, is however an evident tautology.

The word physic and its derivatives have in later times undergone remarkable changes in their application. We speak of physical geography, meaning the natural features of the earth, of physical strength and physical life, and, borrowing a French expression, we call the physique of a man all that relates to the complex human organism and its processes. In our text-books of science, however, we find a conventional use of the word physics in a far narrower sense, where it is restricted to the study of the general properties of inorganic bodies, and their relation to gravity, heat, light and electricity. Such relations are called physical, and are distinguished alike from those called chemical and others which are designated as vital or organic. Yet the professor who talks of physical as distinct from chemical or vital problems, will at the same time speak of his physical as contrasted with his mental condition; referring thereby not only to the activities belonging to his own domain of study, but to those which concern also chemistry and organic life. This same student calls himself in English a physicist and in French a physician (*physicien*). The latter word in the French language had however of old another meaning, and signified a teacher or a practioner of the art of healing diseases, a meaning still retained in our English speech, where physician and doctor of physic are common terms for a practitioner of medicine or a mediciner, as he was of old correctly called. The origin of this use is to be sought in the wider acceptation of the word physic and physics by Greek and Arabian students who, taking all nature for their province, were in the broadest sense of the term, physicians or naturalists, and who applied their knowledge alike of the inorganic and the organic world, to the treatment of disease and the alleviation of human suffering. It was Hippocrates, well named the father of medicine, who first taught that the true method of preserving health and of healing disease was to be found in the study of nature in all its relations. Only those who thus practice the healing art are entitled to the name of physicians or medical physicians. It was by an easy transi-

tion from this conception that the art thus exercised came to be called the practice of physic, that is to say of nature, and that the drugs used in the treatment of disease were themselves often spoken of as physic.

The history of the word physiology is not less curious than that of physic. To the beginning of our own century it still kept the old sense in which it was used by the writers of classic antiquity, as meaning the study of nature in general. The physiologist was something more than what we understand in modern speech by the term naturalist, now generally limited to the student of organic nature ;—and included in the range of his studies all natural phenomena. In Newton's time, terrestrial, atmospherical and astronomical problems, as well as mineralogical, botanical and zoological investigations, were classed under the general title of physiology. There was thus a physiology of the inorganic as of the organic world, a terrestrial and a celestial physiology.

It is by a limitation analogous to that which we have already pointed out that, in our own time physiology has come to be popularly understood to refer to the processes and functions of vegetable and animal organisms; while the simpler processes of inorganic nature are included under the title of physics. Thus, by a curious anomaly in language, two terms having the same etymology, and originally synonymous, have come to be used in senses antagonistic and mutually exclusive of each other ; physical being now generally employed in didactic language to relations which are to be distinguished from those now designated as physiological. Thus, in our schools we speak of physical research and a physical laboratory, meaning thereby something wholly distinct from physiological research and a physiological laboratory wherein are made investigations of vegetable or of animal organisms; yet the professor of animal physiology will still (like the professor of physics) in ordinary speech use the adjective physical in its wider sense to designate all the material activities of the human organism.

The words physic, physical and physiology properly apply to the world of nature as a whole. The study of nature as generally defined, presents two great divisions, the inorganic or mineral, and the organic. This latter

includes both the vegetable and the animal. These two, notwithstanding the apparently close affinities between the lowest forms of each, are, on the whole, clearly distinguished. We thus arrive at the three great divisions commonly called kingdoms of nature, the mineral, the vegetable, and the animal. These distinctions are found at the basis of what we appropriately call Natural History, that is to say, the history or the knowledge of natural bodies. The student of these notes the density, cohesion, color and geometric forms of mineral species, and the details of structure in plants and animals. From the observation of all these characters, and the consideration of differences and resemblances, men have constructed systems of classification in mineralogy, botany and zoology ; have devised a terminology and a nomenclature ; and have thus, in each of the three kingdoms of nature, organized a body of knowledge which we designate as systematic and descriptive mineralogy, botany and zoölogy, or the physiography of minerals, plants and animals ; the study of which, as a whole, is sometimes conveniently comprehended under the title of General Physiography, that is to say a description of nature. This, in its wider sense, includes not only the individual objects belonging to each one of the three kingdoms of terrestrial nature, but the earth as a whole, including geography and geognosy, and extending its field into other worlds, embraces descriptive astronomy.

Having thus laid the foundation of the knowledge of natural objects by a study of their sensible characters we proceed farther to investigate their properties and functions; in other words, their various activities, the changes to which they are subject, their origin, growth and decay.

All of these phenomena may be conveniently considered under three heads. The first of these includes the relations of natural objects to gravity, cohesion, light, heat, electricity and magnetism, and it is these simple non-chemical relations alone which, as we have seen, are frequently designated as physical, a term which in this connection may perhaps be advantageously replaced by *dynamical*, since some of the highest authorities include the phenomena in question under the general title of dynamics. Under the second head come the chemical

changes of matter, and it may be said that the whole history of inorganic nature, or of the mineral kingdom, is comprised in its dynamical and chemical relations. It is not until we enter the organic world that we find other forms of activity manifested in the phenomena of irritability, assimilation, growth and reproduction, wherein to dynamical and chemical processes are superadded those which are peculiar to the organic world, and which are distinguished as vital or *biotical*. It is not our plan or purpose to consider in this connection the great question of the nature of life, but I must here record my conviction that the activities which appear in a growing organism are but manifestations on a higher plane, and with more perfect means, furnished by a more complex structure, of an energy which already existed in the unorganized matter of the mineral kingdom.

The student who has begun by investigating natural objects in the way which has just been pointed out, will not be content to rest in this knowledge. Having learned the structure, properties and mode of formation of the crystal, and the chemical changes of which its constituents may be the subject, he is led to study the relations of the various parts of the mineral world to each other, to consider their growth, their decay, and their past and their future history. Coming next to the study of the organic world, he finds therein relations still more complex; the beginnings of life, the genesis of organized individuals; the assimilation by these of extraneous matter, whether from the organic or the inorganic world, which constitutes nutrition, and the mutual interdependence and interaction between the mineral, vegetable and animal kingdoms, engage his attention. Not less wonderful are the laws of growth and reproduction, the morphological changes of organisms, and the subtile relations which connect the lowest with the highest forms in organized nature. This study of the laws and processes by which the material world is fashioned gives us the reason or the logic of nature, a phrase synonymous with physiology. We have thus presented to us two aspects of the study of nature, the one descriptive, which we designate General Physiography or Natural History, the other philosophical, which is appropriately called General

Physiology or Natural Philosophy, the Physiophilosophy of some writers.

From the foregoing analysis it will be apparent that each one of the three great kingdoms of nature has its physiology as well as its physiography; that we cannot with propriety restrict the former term to the organic world, but that while we speak of vegetable and animal physiology we must also recognize a physiology of the inorganic world. Apart from the consideration that many of the processes which are generally comprehended under the head of organic physiology are the same with those exhibited by the inorganic world, being essentially dynamical or chemical in their characters, it can be shown that the various processes of the mineral world present many analogies with those of organic life, and these it is which may be appropriately said to belong to the domain of mineral physiology. More than this, these physiological processes are often so connected with the organic world on the one side and the inorganic on the other, that they appear as necessary and contiguous links in the great chain of terrestrial activities.

The growing plant gathers from the earth, the air and the waters the mineral elements which, in its laboratory, are converted into more complex chemical species, and these, in their turn, are transformed into stem, foliage, flower and fruit. The compounds thus elaborated in the vegetable organism may become the food of herbivora, and through these indirectly make part of the bodies of carnivorous animals or of man himself. Sooner or later, however, the plant or the animal, in obedience to the universal law of change and decay, is once more resolved into inorganic forms, which are ready to enter again into the round of the organic circulation. The organism reverts to dust, or rather, except a small proportion of earthly matters, to the atmosphere; which, as has been happily said, is the cradle of the plant and the grave of the animal. Such, in brief, are the processes of the organic world and their relation to inorganic nature, which, viewed from the standpoint of the chemist, appear as metamorphoses of the mineral world through the intervention of organisms. There are, however, other great and important processes of transformation and distribution in mineral matter in which the organic world does

not intervene, or at best, plays but a secondary and indirect part through the products of its partial decay. Besides what we have just called the organic circulation of matter, there are three others which we may designate as the terrestrial, the aërial and the oceanic circulations. No one of these is independent of the others, and all of them are, in fact, ultimately subordinated to the last named; yet each may be considered by itself, and will be found to present a history of physiological processes replete with interest and instruction. The terrestrial circulation especially, as I shall endeavor to show, frequently offers suggestive analogies to the circulatory processes in plants and animals. It is, moreover, through this circulation that some of the most important mineral masses in nature have been generated, and deposits of precious metals, ores and gems have been derived from the great bulk of the earth's crust. The study of the terrestrial circulation will thus introduce us to one of the most important chapters in the chemical history of the globe.

Without attempting to trace the chemical elements of our earth to the fire-mist or nebulous matter from which a modern theory with great plausibility conjectures their origin, and without inquiring into the chemistry of a cooling globe, which however presents a legitimate field of speculation, I invite you to follow me backwards in imagination to a time which is sometimes called the Primary or Archæan period, or the Eozoic age, in geological history, when there were already a solid and cooled earth, land and an ocean, in the waters of which animal and vegetable life may be supposed to have been not less abundant than they are in our present seas. At this time the oldest known series of rocks, that called the Laurentian, to which belong the granite-like gneisses of the Highlands of the Hudson, the Adirondack hills and the Laurentides of Canada, from which this ancient series takes its name, —was already in existence. While from the seas of that time were being deposited the materials of a newer series of rocks, we have evidence that already the beds of this ancient gneisses were in their present contorted and folded position and had the same mineral composition as to-day. Interstratified with them were already the crystalline limestone with graphite, and the great beds of

iron-ore which to-day constitute the chief mineral wealth of the Laurentian series of our region. These, and similar rocks, so far as we know, formed everywhere the dry land and the ocean's bottom. At that time the crystalline schists which form the greater part of New England and Eastern Canada ; the slates, limestones and iron-ores of Dutchess county and the great Appalachain valley were not yet formed ; the vast series of paleozoic rocks, some 40,000 feet in thickness which includes the salt and gypsum and iron-ores of central New York, and the coal and petroleum of Pennsylvania, had not been laid down. The precious stores of lead and silver ores in Colorado, Utah and Nevada, the mineral wealth of the Sierras, were not ; for the very rocky strata in which all these deposits are included were as yet unformed. All of the great geological series just enumerated have been built up since the Laurentian age, and in great part from the ruins of portions of the rocks previously existing, and owe, with limited exceptions, their deposition and their accumulation to the action of water. The changes and revolutions of the earth's surface during these long ages are written on the rocky strata, and the remains of organisms which these enclose, tell the history of the successive generations of plants and animals which have flourished and passed away. Time would fail us to consider the differences in texture and in composition between these later formed rocks and the more crystalline strata of Eozoic time, or to speak of the great masses of unstratified crystalline rocks, such as the granites of New England and the diabases of the Palisades, both of which are evidently posterior in origin to the stratified rocks among which they have been intruded in a heated and more or less molten condition, not unlike the volcanic rocks of more recent times. The interstratified masses of aqueous origin are often distinguished by the obvious name of *indigenous rocks*, while the intruded masses are sometimes spoken of as *exotic rocks*. These, from their resemblances in composition to the older stratified rocks, are conjectured to be no other than portions of the latter which have been softened by heat in the depths of the earth, and in this state forced upward among the overlying rocks.

We have thus distinguished in the earth's crust two classes of rock-masses; the first formed after the manner of clays, sands, marls, and peats, or like rock-salt and gypsum from the drying-up of salt-water basins, as in great deserts. These indigenous rocks may be either crystalline or uncrystalline. The second or exotic class, for the most part crystalline in character, consists of fused or softened matters which have come up from below, and have either occupied rifts or fissures in the previously formed rocks, or have overspread them.

There is, however, a third class of rock-masses distinct from both of the preceding in their origin and mode of formation. For the most part crystalline in character, they occupy, like the exotic rocks, fissures or other cavities in previously formed rocks, but give evidence that instead of having been introduced at one operation in a softened form into their present places, they have slowly grown there by accretion, for which reason they have been called *endogenous rocks*. These masses, in their mode of origin are like the solid deposits from certain mineral springs, or the incrustations in steam-boilers, and though small in extent as compared with the indigenous or exotic rocks, (in both of which they may occur), are important alike from their mineral composition, and from the light which they throw on terrestrial processes. To these endogenous masses belong the so-called granitic veins made up of the elements of ordinary granite, such as feldspars, micas and quartz, but often containing tourmaline, topaz, beryl, zircon and other gems, as well as ores of tin, and some other metals. To this same class also belong the mineral lodes from which are derived the greater part of our gold, silver, copper and lead. Endogenous masses may be described as for the most part as either granitic, quartzose or calcareous in character, but as including at the same time, in a more or less concentrated form, many of the rarer chemical elements of the earth's crust. While the silica, alumina, lime, magnesia, alkalies and iron, which make up the chief part of the solid rocks, are everywhere distributed with impartial abundance, there are other elements, often of great value to man, which are present in the great bulk of the earth in such insignificant amounts that their proportion seems infinitely small. Aided by the spectroscope and

other delicate modes of research, we are enabled to detect their presence disseminated in solid rocks or dissolved in the ocean's waters, but we find them concentrated in the endogenous rocks. Not to mention silver and gold, copper and tin, which at once suggest themselves, we there find lithium, caesium, glucinum, yttrium, cerium, zirconium, tantalum, uranium, tungsten, molybdenum, and other rare elements accumulated in such quantities as to make up a large part of certain mineral species peculiar to these endogenous rocks.

Whence have come these rare elements, and what is the source of the matters which constitute these veinstones? As I have said before, the great bulk of an endogenous rock may consist of the same elements as a limestone, a sandstone, a gneiss or a granite, from which rocks, however they differ, alike by their structure and by the presence of rare and peculiar mineral species. The origin and the composition of these veinstones thus assume a great interest to the student of the physiology of the earth. As the forces at work in a growing plant determine the secretion in one part of its structure of sugar and acids, in others of a bitter principle, of aromatic oil, and of coloring matter, all of which we may find within the rind of an orange, so in the earth's crust have been deposited, in different parts, granitic veins, calcareous veins and quartz veins, each carrying its own peculiar ores or other mineral species, the work of successive and independent processes, often at widely separated intervals of times.

To attempt a detailed description of these various processes would involve a discussion of dynamical and chemical principles requiring a volume, but I may call your attention to some fundamental points which may indicate the general nature of the problems presented, and the mode of their solution. Of these, the first is the solvent power of water. Of those bodies which are regarded as insoluble, the greater part are soluble to a small extent under ordinary conditions, and to a much greater degree with increased temperature and pressure. Again, very many such nearly insoluble bodies are found to assume, under certain conditions, a soluble condition, from which, however, they readily pass into one of comparative insolubility. This two-fold character is illus-

trated by the familiar case of albumen, which, as found in the serum of the blood or the white of an egg, is readily soluble, but by a gentle heat coagulates, and then becomes a white insoluble solid. Among mineral species capable of assuming such a soluble condition are the constituents of some of the hardest and most insoluble crystals found in veinstones. Rock-crystal or quartz, the ruby or corundum, tinstone, rutile and specular iron ore are examples of this; since the silica, alumina, and the oxyds of tin, titanium and iron, of which they are severally composed, are all readily obtainable in conditions in which pure water is capable of dissolving several hundredths of its weight of them. Many other oxydized bodies, more complex in composition than these, are susceptible of assuming a similar condition, and the same is true of even of metallic sulphids, as sulphid of arsenic. It is certain that this capacity of assuming a soluble condition is much more general than has been supposed, and it may here be noticed that although the soluble forms are generally what is called collodial or jelly-like in character, there are many examples of bodies where temporary solubility is apparently independent of a collodial condition.

Again, it is well known that heat in many cases favors solution, as in the case of sugar, alum and most salts. There are, however, not wanting instances in which an increase of temperature does not augment and even diminishes the solvent power of water. Hence, while most watery solutions saturated when hot deposit crystals of the dissolved body in cooling, there are other solutions, which when saturated in the cold deposit crystals if the temperature is raised. Examples of this are seen in gypsum and in other sulphates. The presence of many alkaline and neutral salts in water in like manner serves to increase its solvent power for certain bodies, while in other cases their presence is not less efficacious in preventing solution. Sulphuretted hydrogen and carbonic acid also augment the solvent power of water for many substances.

In considering the solvent power of waters within the earth's crust, we must farther remember that as we go downward there is a more or less regular increase of temperature, equal to about one degree of Fahrenheit for

each fifty feet, and that at 9000 feet there will be an augmentation equal to 180° F., which added to the mean temperature at the earth's surface would considerably exceed 212°, the boiling point of water at the ordinary pressure. Now, we are certain that water in the terrestrial circulation descends to much greater depths than this, and thus, in a liquid state, reaches correspondingly higher temperature, at which, as we know from experiments made in our laboratories in sealed tubes, its solvent powers are greatly and often unexpectedly exalted.

In estimating the solvent power of water at great depths another principle comes into play, that of the pressure exerted by the column of water, which for each 1000 feet in height is equal to thirty atmospheres. The process of solution in water is for most substances attended by contraction, the volume of the solid dissolved being lost in that of the liquid, so that when one hundreth of common salt, for instance, dissolves in water, the condensation which takes place is far greater than could be brought about in the liquid by any mechanical means at our command—water being nearly incompressible. Experiments have, however, shown that external force may aid solution, by favoring this process of condensation; water under great pressure having been found to take into solution larger amounts of certain matters, such as common salt, than it would at the ordinary pressure. This we should expect to find the case for all such bodies as lose bulk in the process of solution, while the reverse would hold for such as expand in dissolving. The relations of pressure to solution are thus similar to those offered by the fusion of bodies under pressure; by which, as we know experimentally, the melting-point of such as expand in melting is raised, while for those which contract in melting it is depressed. It is evident then, that hydrostatic pressure at considerable depths must coöperate with increased temperature to promote the solubility of many substances in water and in the watery solutions which are circulating through the earth's crust. Of the many chemical reactions which take place at these great depths under the conditions already set forth we can form but inadequate notions. Yet experiments made in the laboratory of the chemist with heated solutions confined in tubes of glass or of metal have shown that it is possible thus to

crystallize various ores and spars, and to produce artificially a greater number of the mineral species found in veinstones. The curious processes of selection and elimination by which so many of the rarer elements are gathered from the great mass of the earth through which they were originally distributed, would require for their discussion a more extended study than our present limits permit, but we may remark that selective diffusion and osmosis doubtless play an important part therein, as they certainly do in many processes in the organic world.

The experiments in the chemist's laboratory, conducted at temperatures considerably above the boiling point of water, enable us to produce many mineral species in a short time, but we have evidence that similar results are produced, though more slowly, at much lower temperatures. The baths constructed by the Romans with brick and mortar at various hot springs in France, less than twenty centuries since, have within the last few years been found to contain in the cavities of the masonry a great number of crystallized mineral species identical with those met with in mineral veins, all of which have evidently been formed within that time by the action of the mineral waters at temperatures considerably below that of boiling. Again, in California and Nevada, thermal waters still bring to the surface dissolved silica, which they deposit in the fissures of the rocks, together with sulphuret of mercury, pyrites and gold, thus giving rise to veinstones closely related in composition to the more ancient ones to be found in the rocks near by. The great quartz vein of that region, known as the Comstock lode, has been formed in times geologically very recent, by the action of hot waters resembling those now flowing in its neighborhood.

To explain the origin of the various mineral waters which have formed the veinstones, would involve a discussion of the whole doctrine of the terrestrial circulation. It may be said in a few words that the rocks of the earth's crust are more or less permeable to water, which filters through porous beds or flows through joints or fissures, carrying with it gases dissolved from the atmosphere, and the results both of organic and mineral decay, very complex and variable in composition, taken

up in its course. The downward flow of these waters, progressively augmenting in temperature, continues until it reaches depths determined by accidents of stratification or by lines of fracture. Thence, in obedience to hydrostatic laws, it rises again to the surface, sometimes through porous beds, but more generally along the lines of fracture, due to terrestrial movements. These fissures are the veins, which become in time incrusted and filled up by deposits of mineral matter from the ascending waters. The separation of these is due to the diminution of the solvent power of the water as it cools in its upward course and is moreover relieved of the pressure which had augmented its capacity for solution. To this we may often add the chemical effects of the influx at various points into the channel of divers substances dissolved from other strata, bringing into play new affinities in the original solution.

The progressive incrustation and the final obliteration of the channels as these become filled with veinstones and the water ceases to flow, or else seek new channels, is made apparent by the banded structure often seen in these deposits, which frequently display bilateral symmetry in the arrangement of the successive layers, and moreover often include in their centre geodes or imperfectly filled cavities, generally lined with crystals. In this connection must not be forgotten the mechanical force of crystallization from mineral solutions, which like freezing water, often serves to open joints in the rocks. The walls of veins sometimes show evidences of this rending and disrupting force of crystallization.

I have thus endeavored to place before you some of the principles involved in the production of veinstones, and to indicate to you how the terrestrial circulation, dependent upon the rainfall and the ordinary laws which regulate the flow of liquids, suffices to dissolve from the solid matter of the earth's crust elements once widely diffused, and to accumulate them by subsequent depositions in the concretionary masses which we call endogenous rocks or veinstones. I cannot forbear to notice an analogy between the formation of these and the process by which a vertebrate animal repairs a fracture in its osseous structure. In this case, the circulating liquids bring to the broken part the dissolved elements of bone, and there

build up a fresh portion, which serves to unite the disrupted fragments and thus to make the limb whole again. In a like manner does the terrestrial circulation repair the fractures in the earth's crust by the formation of veinstones; an example in the mineral world of nature's conservative surgery.

There is another side to the process of growth and production of new rock-masses which we have just considered. The new is built up by the decay of the old, and it would be instructive to study at length the processes of disintegration and solution which are the necessary preliminaries to reproduction and palingenesis. There is however one phase of this destructive metamorphosis of mineral matter upon which I may be permitted to dwell for a few minutes,—that of the subaērial decay of rocks, or their alterations when exposed to the influences of air and moisture. Going back once more in imagination to the time when there were no rocks newer than our ancient Laurentian gneisses, with their accompanying interstratified limestones and iron-ores we discover that there were then no sandstones, no clay-slates, nor in fact anything to represent the vast deposits of uncrystalline sands and clays of later times. All of these are results of a subsequent process of subaērial decay. Slowly but inevitably the solid granites, gneisses and similar crystalline rocks decay like dead trees in a forest. Water and air conjoined cause the breaking up of the feldspars, the hornblendes, and many other mineral silicates which enter into the composition of these rocks, and thus convert these into a crumbling earthy mass. Much of the silica, besides the lime, the magnesia, the potash, and the soda of these minerals, passes into solution, and little more than clay, iron-oxyd and quartz, remain behind in the softened and decayed mass, which has lost one half or more of its weight, and now yields readily to the mechanical action of water, by which it is separated into clay on the one hand and sand on the other. Geological investigations show that such a process of decay has gone on continuously from the Laurentian age to the present, whenever crystalline rocks have been exposed to the action of the elements, and that this process has been the source of all the clay and most of the sand which enter so largely into the com-

position of the uncrystalline strata; the formation of which thus involves the decay of vast masses of the crystalline rocks.

If we follow into the southern states of the Union the great Atlantic belt of ancient crystalline rocks, we shall find that these, which in New England and New York are either bare and ice-worn, or else covered with transported material, are there concealed beneath a cover often one hundred feet or more in thickness, of decayed material, which, although it has lost one-half or more of its weight, still retains its original volume, structure and place, and in its deeper portions includes lumps or cores of crystalline rock still undecayed. It needs but the action of water, such as would result from a gradual submergence beneath an invading sea, to break up these softened rocks, carrying off the clay to be laid down in quiet waters, depositing the sand in the track of the currents, and leaving behind the cores of undecayed rock in the shape of boulders of granite or gneiss—thus producing all the conditions to be seen in our more northern regions, where a denuding process has disturbed and rearranged the results of the sub-aërial decay of the ancient rocks.

That such has been the origin of the mechanical sediments which make up the great bulk of the stratified rocks from the Eozoic age to our own, there can be no doubt, and the history of our granite boulders is clear in the light of these observations. The hard, undecayed crystalline rocks are not readily worn away, but the preliminary process of decay makes the action of eroding agents easy and rapid. Hence it is that in the northern regions, where marine currents and glacial action have done their work, the decayed materials have long since been swept away from the surface of our hills, and that only here and there, in localities sheltered from the eroding agents, as, for example, along the western base of Hoosic Mountain in Massachusetts, do we find any remains of the deep mantle of decayed rocks which once covered our northern hills of gneiss and granite. But when we go southward from Philadelphia, beyond the southern limit of glaciation, we find the covering of decayed rock lying deep over the Blue Ridge, in Virginia and the Carolinas. It would be long to tell the evidence that in past ages this condition of things extended over

the whole Atlantic belt to the northward, and how in the valley of the Mississippi, where the present outcrops of these ancient rocks are eroded, as in the east, we find beneath sandstones of later times portions of the old decayed mantle which had escaped erosion until thus protected. Such a process of decay has always been going on at the earth's surface, and is even now slowly but certainly wasting the hardest rocks.

The usual eroding agents, ice and water, are inadequate to remove great areas of hard rocks unless these have previously been softened by decay, and a careful study of the question led me long since to maintain that the chemical decomposition of rocks is a necessary preliminary to glacial and erosive action, which has removed only already softened materials. From this it follows that the forms and outlines of the sculptured surface thereby exposed would be determined by the varying depths to which the process of subaerial decay had already penetrated the once firm and solid rock. The boulders, the rounded bosses and hillocks, and the closed basins, which are so conspicuous in glaciated regions of crystalline rocks, are due not primarily to glacial erosion, as some have taught, but to previous decay, softening portions of the rocks, the subsequent removal of which has given rise to these outlines. Some of these contours now observed were thus sculptured in very remote geological ages, and later glacial action has done little more than to groove and polish them.

We have already noticed the fact that in this decomposition a large proportion, equal in many cases to more than one half of the weight of the rock, passes into solution in the superficial waters. Of these dissolved matters a certain portion, filtering downward, enters into the terrestrial circulation, but by far the larger part find their way directly into what we have designated the oceanic circulation, which includes alike the rainfall, rivers, lakes, and the sea itself. The dissolved silica, lime and magnesia, have contributed greatly to the building up of stratified rocks, including besides limestones and dolomites many silicated and silicious deposits ; while by the action of the dissolved magnesian and alkaline salts the composition of the ocean's waters has in successive ages been greatly modified.

The part which the atmosphere has taken in these processes is not less important. Through the aërial circulation has come the enormous volume of carbonic acid which has played an indispensable part in the decay of the rocks, and uniting with lime and magnesia has formed the carbonates in the earth's crust, besides furnishing, through the agency of vegetation, all the carbonaceous matters found therein in the forms of coal, petroleum and related bodies. Time will not here permit us to enter into the considerations which lead to the conclusion that this aërial circulation involves not only the immediate atmosphere of our planet but that of other worlds as well; so that through it we are placed in relations of material interdependence with other bodies of the solar system, and even with the remotest realms of space. Such a relation, which was long since conjectured by Newton, I have endeavored to establish by chemical and geological considerations.

And now in conclusion let me say that I have sought in this evening's discourse, to give you some glimpses of the great processes of inorganic nature, as seen in the decay and disintegration of old rocks and the building up of new ones, including more especially the formation of veinstones, with their segregations of rare and valuable ores and gems. I have pointed out the functions in all these processes of the terrestrial, the oceanic and the aërial circulations, which show everywhere a perpetual flux, a ceaseless decay, and a constant renewal; and make it clear that the earth, the waters, and the air, have a physiological history not less wonderful than that of the growing oak or of man himself. To man alone is, however, reserved the distinction that in him matter attains such a perfection of organization that he is placed in conscious relation with the external world, that he learns to comprehend the significance of nature, and to understand the formative processes which have evolved the present order from the primeval chaos. Nay, rising higher still, man becomes aware of an intimate relation with the spirit of nature itself, and feels, in his moral consciousness, that this spirit is not only the life of all material things, but the power, not ourselves, which makes for righteousness.